**AMERICAN BUREAU OF SHIPPING**

# VISUAL REFERENCE STANDARDS

# FOR WELD SURFACE

# CONDITIONS

(PHASE I)

**APRIL 1983**

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## CONTENTS

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## FOREWORD

The purpose of this report is to present the results of one of the research and development programs which was initiated by the members of the Ship Production Committee of The Society of Naval Architects and Marine Engineers and financed largely by U. S. Maritime Administration and Newport News Shipbuilding. The effort of this project was directed to the development of three dimensional sample illustrations of weld surface conditions, applicable to visual weld inspection.

Mr. M. I. Tanner and Mr. B. C. Howser of Newport News Shipbuilding, were Program Managers. Mr. B. L. Alia and Mr. I. L. Stern of the American Bureau of Shipping (ABS), were Project Managers, and Dr. D. Ku, Mr. R. Waite and Mr. D. Cantore of ABS were the Principal Investigators.

Special acknowledgement is made to the members of Welding Panel SP-7 of the SNAME Ship Production Committee who served as technical advisors in the preparation of inquiries and evaluation of subcontract proposals and to Newport News Mr. M. I. Tanner for making possible the report compilation. Appreciation is expressed to the following shipyards who contributed weld samples:

- Avondale Shipyards, Inc.
- Bath Iron Works Corporation
- Bay Shipbuilding Corporation
- Newport News Shipbuilding
- Pennsylvania Shipbuilding Company (Sun Ship)
- Portsmouth Naval Shipyard
- Todd Pacific Shipyards Corporation

## 1.0 ABSTRACT

Samples were produced illustrating three types of weld surface conditions at three levels of severity in butt and fillet welds. The samples can be related to existing descriptive acceptance standards used in the marine industry, and could form the basis for a guide for the evaluation of weld surface conditions which could be applicable to the various structural and pressure vessel requirements of the marine industry. The use of such illustrations, replicated as plastic models, could reduce the frequency of making physical measurements of weld surface conditions, and also reduce the subjective considerations in evaluating weld surfaces. This phase of the project covers the conditions of cluster porosity, scattered porosity, and undercut.

## 2.0 INTRODUCTION (PURPOSE OF WORK)

Visual inspection is the most extensive nondestructive method used for weld evaluation. Judgements as to the acceptability of welds based on visual examination may be controversial in that existing codes and specifications lack sufficiently clear and objective criteria for certain-weld surface conditions. While some codes define the acceptable level of some surface conditions quantitatively (e.g. size and number of pores, depth of undercut, etc.), others use general descriptive terms (e.g. "reasonably free from undercut and overlap"). In some cases, however, subjective judgement is involved to the extent that experts may not always agree on the acceptance of a given weld evaluated against a descriptive standard. Consequently, there is an apparent need to reduce the subjective considerations involved and to augment descriptions in existing codes and specifications.

In the course of the deliberations of the SNAME SP-7 Panel, it was agreed that a viable approach to meeting this need would be the development of plastic models of welds with various gradations of different weld surface conditions and with supplementary descriptions.

Visual examination of welds also involves making tedious and time-consuming measurements and the potential value of appropriate samples illustrating weld surface conditions for reducing the frequency of making these measurements could provide an additional benefit.

This report represents the initial phase of an overall program to develop appropriate visual illustrations of weld surface conditions which could be used as reference standards by shipyards, specification writing bodies, technical societies and fabricators. The term "illustrations of weld-surface conditions" will be used in this report in preference to the term "reference standards" to better reflect the intended use of the samples.

## 3.0 OBJECTIVES

The objectives of the program were as follows:

a) To develop samples illustrating various weld surface conditions with graded degrees of severity. The initial phase was to include the conditions of undercut, porosity, roughness and contour.

b) To relate the illustrations of weld surface conditions to present marine standards.

c) To present a basis for utilization of the samples illustrating weld surface conditions for marine applications by governmental organizations and the American Bureau of Shipping (ABS).

The related objective, outside the scope of the initial phase, was to replicate the selected weld surface conditions as plastic models.

## 4.0 APPROACH

To augment the descriptive visual acceptance standards presently used in the marine industry, the following standards were addressed (pertinent sections are summarized in Tables I and III).

1. American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels
2. U. S. Dept. of the Navy NAVSEA 0900-LP-O03-8000 Surface Inspection Standard for Metals
3. American Society of Mechanical Engineers (ASME) Section VIII - Division 1 Pressure Vessels
4. American Welding Society (AWS) D1.1 Structural Welding Code - Steel (Tubular Structures)

The initial approach was to produce samples illustrating the following surface conditons in butt and fillet welds:

Undercut
Porosity
Roughness
Contour

In the course of work, it became evident that porosity should be expanded to two categories (scattered and cluster) and, roughness and contour deferred. Only one type of condition was to be represented in each sample. The samples provided by various shipyards were to represent marginally acceptable and marginally rejectable levels applicable to the particular production work of each participating shipyard. A total of

350 samples were-provided by 7 shipyard members of the SNAME SP-7 Panel. The selection of representative samples illustrating surface conditions was to be based on the consensus of the members of SNAME SP-7 Welding Panel.

## 5.0 PROCEDURE

Samples were first evaluated using AWS D1.1 criteria for undercut and porosity. This first selection of samples represented the minimum levels acceptable according to AWS D1.1. Additional samples were selected to represent one higher and one lower quality level.

The three levels of undercut, scattered porosity, and cluster porosity reflected by the samples were measured and then defined as indicated in Table II. Each sample was machined to the following dimensions:

Butt weld - 6" L by 2" W
Fillet welds - 6" L

The six inch length was chosen because many codes address the allowable distribution of weld surface conditions in multiples of six inches of weld length. The selected samples, photographed at 0.5 and 2X magnification, are shown in Figures A through F. The relationship of each sample to the acceptance criteria governing surface conditions in various codes is shown in Table III.

Selection of samples illustrating roughness and contour was deferred to a later phase of the project for reasons indicated in Section 6.0.

## 6.0 DISCUSSION

The use of illustrations or replicas of conditions to augment descriptive text has precedent in many areas of materials and welding, for example: gas cut edge conditions, surface roughness comparisons, internal weld quality (reference radiographs), internal material quality (reference macrophotographs) and so forth. The value of such illustrations is in minimizing differences of opinion in interpreting written text. Another-potential benefit is that the use of illustrative samples or models permits inspection to be made rapidly, with a minimum need for gage measurements, thereby reducing inspection costs.

Five weld surface conditions were considered: undercut, scattered porosity, cluster porosity, roughness and contour. The first phase of the program covers the first three conditions. As there are no clear code definitions for measurable levels of cluster porosity, the relationship of the samples of cluster porosity were not directly related to the codes.

A consensus as to the descriptive or quantitative criteria to more clearly delineate the conditions of contour or roughness could not be reached, and their consideration was deferred to a subsequent phase of the project after such clarification is accomplished. Depicting relative levels of roughness is made difficult by the imprecise language to describe the condition in existing codes. For example:

ASME Section VIII Division 1 states provided the weld is free of coarse ripples, grooves, overlaps, abrupt ridges or valleys . . . Clarification and quantitative expression as to what is “coarse” and “abrupt” would be a necessary adjunct to the illustrative samples for this condition.

Reaching a consensus on the condition of contour is complicated by the fact that “contour” can be considered as a variety of proportions of one or more conditions, i.e. convexity/concavity, insufficient throat, reinforcement, overlap and reentrant angle. It is apparent that a single set of samples cannot represent the conditions of roughness and contour. The variety of sets of samples needed was considered beyond the scope of the initial phase of the program.

The relationship between the specific conditions represented by the samples and the specific requirements in the codes considered is shown in Table III. As indicated therein, a code may have different requirements for fillet welds and for butt welds, and may not permit any level of a particular type of defect; with respect to the A, B, and C levels of illustrations proposed, an additional level “O” should be used to designate an absence of conditions. For example: AWS D1.1 requires that “butt welds transverse to the direction of computed tensile stress”, be free of porosity; Table III indicates a level “O” would be the appropriate illustrative sample.

Table IV shows how the levels of severity represented in the samples relate to the codes, and how the codes relate with each other.

It should be understood that the conditions illustrated represent levels of severity that may or may not be acceptable depending on the pertinent code or application, as well as their overall frequence of occurrence. There are instances where a shipyard or designer may specify requirements in excess of an allowable code to take into account special requirements: i.e. the presence of porosity may be unacceptable if certain coatings were required to be applied to welded structure or for watertight applications. The conditions illustrated are neither intended as quality targets in the training of welders nor to represent the general level of quality desired in production, in that the conditions should ideally be absent, but as a practical matter may be tolerated in isolated instances within prescribed limits.

In the course of the program, the value of the illustrative samples as enhancers of the written text of various codes and specifications was verified by evaluation of the informal comments of people highly qualified in weld inspection, who were shown the relationship between the illustrative examples and written text of the specifications under consideration. The ease of evaluation using the samples was clearly apparent.

NAVSEA 0900-LP-O03-8000 applies to structural applications in non-combatant surface ships. ASME applies to marine boilers and pressure vessels, and AWS D1.1 is frequently used for offshore structures. The samples selected illustrate the conditions of undercut and porosity addressed in these codes.

In connection with commercial ships, it may be reasonable to relate the classes of illustrated surface conditions in samples to the structural application categories as defined in the ABS Rules for Building and Classing Steel Vessels and Rules for Building and Classing Mobile Offshore Drilling Units. For example; level O (absence of conditions) or level A of a given surface condition might be related to important welds in areas of a ship or offshore structure where special application materials are required by the ABS Rules, levels A or B for other important materials, levels B or C for secondary structures and level C for nonstructural applications.

An equally feasible approach would be to relate the levels A, B and C of the illustrative models to the qualities refleeted by the ABS Rules for Nondestructive Testing, which relate Class A and B standards to welds in various locations and applications in ships and other marine structures.

It should be realized that the developed samples represent a first step in producing a more complete set of samples illustrating commonly encountered weld surface conditions.

Illustrative samples should also be developed to reflect variables such as welding process, welding position, and weld size, However; it is believed a guide can be developed on the basis of the samples already selected; extension of the guide to cover roughness and contour will be accomplished in a subsequent phase of the program.

## 7.0 CONCLUSIONS

1. Samples illustrating weld surface conditions have been developed which can be related to and augment written welding codes and their potential value in the development of a guide for the marine industry has been indicated.
2. Six sets of samples showing three levels of severity of surface condition for undercut, scattered porosity, and cluster porosity in butt and fillet welds, have been produced.
3. Selected conditions of undercut and scattered porosity can be related to existing descriptive standards for visual inspection presently used in the marine industry. Cluster porosity is not specifically addressed by any of the codes studied; however, the severity levels selected for this condition could be a basis for incorporation into existing codes or future guidelines.
4. The use of such samples as visual reference standards to reflect quantitative limitations of surface conditions indicated in a code or shipyard specification could reduce costs in the marine industry by reducing the amount of physical measurements on weld surfaces.

## 8.0 RECOMMENDATIONS

It is recommended that the proposed basis for visual illustrations of weld surface conditions, i.e., descriptions of weld surface conditions accompanied by replicas of these conditions be presented to pertinent code writing bodies for their consideration for use in connection with published codes.

## 9.0 FUTURE WORK

1. Replication of the selected and adopted illustrations of weld surface conditions as plastic models should be pursued.
2. The next phase of the program should involve consideration of weld surface roughness and weld contour (including reentrant angle, overlap, convexity and concavity).
3. Subsequent phases of the project should address illustrations of surface condition relatable to various welding process, welding position and weld thickness.
4. It is expected that the samples, in combination with appropriate text, will be submitted for consideration for Ship Classification Society use as a guide for the evaluation of weld surface conditions.

## TABLE I

### SUMMARY OF ACCEPTANCE STANDARDS

### (UNDERCUT)

| | |
|---|---|
| NAVSEA<br>0900-LP-003-8000<br>Para. 5.2.1.6 | Class 1 1/64″ or 10% base metal T, whichever is less<br>Class 2, 3 1/32″ or 10% base metal T, whichever is less |
| AWS D1.1<br>Tubular<br>Para. 10.17.1.5 | 0.01″ max. transverse to primary tensile stress<br>1/32″ max. other locations |
| A B S<br>Section 30.5.8 | "The surfaces of welds are to be . . . reasonably **free** from undercut and overlap" |
| ASME<br>Sec. VIII Div. 1<br>UW-35 | 1/32″ max. |

## TABLE I (CONTINUED)

### SUMMARY OF ACCEPTANCE STANDARDS

### (POROSITY)

| | |
|---|---|
| NAVSEA<br>0900-LP-003-8000<br>Para. 5.3.2.2 | 1/8″ max. - varies with T<br>4 or more rounded aligned separated by 1/16″ or D whichever is greater |
| AWS D1.1<br>Tubular<br>Para. 10.17.1.6/7 | Fillet: Sum of Ø 3/8″ max. / linear inch<br>Sum of Ø 3/4″ max. / 12 inches<br>Butt : None when transverse to primary tensile stress. Other areas: same as fillet |
| ABS<br>Section 30.5.8 | “The surfaces of welds . . . are to be regular and uniform” |
| ASME<br>Sec. VIII Div. 1<br>Appendix 8<br>Para. 8.3, 8.4 | 4 or more rounded defects (L < 3XW) separated by l/16in. (1.6 mm) or less (edge to edge) |

**TABLE II**

**WELD SURFACE CONDITIONS - SEVERITY LEVELS SELECTED**

**- BUTTS AND FILLETS -**

**UNDERCUT**

| | |
|---|---|
| Level O: | Not present |
| Level A: | 1/64 in. deep continuous |
| Level B: | 1/32 in. deep continuous |
| Level C: | 1/16 in. deep continuous |

**SCATTERED POROSITY**

| | |
|---|---|
| Level O: | Not present |
| Level A: | 4 pores 1/32 in. maximum diameter |
| Level B: | 4 pores 1/16 in. maximum diameter |
| or | 7 pores 3/64 in. maximum diameter |
| Level C: | 4 Pores 1/8 in. maximum diameter or equivalent area |

**CLUSTER POROSITY**

| | |
|---|---|
| Level O: | Not present |
| Level A: | multiple pores 1/32 in. maximum diameter within 1/4 in. |
| Level B: | multiple pores within 1/2 in. |
| Level C: | multiple pores within 1 in. |

**NOTES** :

1. All of the above definitions are per 6 in. of weld.
2. Level O is to be used for each condition to represent a weld which is free of the surface condition under consideration.

**TABLE III**

**RELATIONSHIP BETWEEN EXISTING ACCEPTANCE STANDARDS & SELECTED SAMPLES**

**- UNDERCUT -**

| **EXISTING STANDARD** | **APPLICABLE SAMPLES** |
|---|---|
| AWS D.1.l<br>Section 10.17.1.5<br>Requirements | |
| Undercut shall be no more than 0.01 in. (0.25mm) deep when its direction is transverse to primary tensile stress in the part that is undercut, | LEVEL A (1/64 in. Undercut) (considered meeting 0.01 inch requirement for butts and fillets from AWS) |
| nor more than 1/32 in. (0.8mm) for all other situations | LEVEL B (1/32 in. undercut) for butts and fillets |

## TABLE III CONTINUED
## - UNDERCUT -

| EXISTING STANDARD | APPLICABLE SAMPLES |
|---|---|
| NAVSEA 0900-LP-003-8000<br>Paragraph 5.2.1.6<br>Requirements | |
| CLASS 1<br><br>The maximum undercut shall be 1/64 - inch or 10% of the adjacent base metal thickness, whichever is less | **LEVEL A (1/64 in. undercut) for butts and fillets (thickness ≥ 5/32 - in.)** |
| CLASS 2 and 3<br><br>The maximum undercut shall be 1/32 inch or 10% of the adjacent base metal thickness, whichever is less. | **LEVEL B (1/32 in. undercut) for butts and fillets thickness ≥ 5/16 - in.)** |
| For base metal thicknesses 1/2 - inch and greater, undercut up to 1/16 - inch is allowed if the accumulated length of undercut exceeding 1/32 - inch does not exceed 15% of the joint length or 12 - inches in 36- inches length of weld whichever is less. | LEVEL B (1/32 in. undercut) (Note 1)<br>**Level C (1/16 in. undercut) (Note 1)**<br>for butts and fillets |

**NOTE** : (1) These weld samples illustrate the magnitude of the defect. The permissible distribution is specified in the specification.

## TABLE III CONTINUED
### - UNDERCUT -

| EXISTING STANDARD<br><br>ASME<br>Section VIII Div. 1<br>Paragraph UW-35<br>Requirements | APPLICABLE SAMPLES |
|---|---|
| The reduction in thickness shall not exceed 1/32 in. 0.8mm) or 10% of the nominal thickness of the adjoining surface, whichever is less. | LEVEL A (1/64 in undercut) for butts and fillets (5/32 in. $\geq$ thickness $\leq$ 5/16 in.<br><br>LEVEL B (1/32 in. undercut) for butts and fillets thickness $\geq$ 5/16 in.) |

**TABLE III CONTINUED**

**-SCATTERED POROSITY-**

| **EXISTING STANDARDS** | **APPLICABLE SAMPLES** |
|---|---|
| AWS D.1.l<br>Section 10.17.1.6<br>10.17.1.7<br>Requirements | |
| Fillet Welds<br>The sum of diameters of piping porosity in fillet welds does not exceed 3/8 in. (9.5mm) in any linear inch of weld and does not exceed 3/4 in. (19.0mm) in any 12 in. (305mm) length of weld. | LEVEL B (4 pores 1/16 in.) (Note 1) for fillets<br>LEVEL C (4 pores 1/8 in.) (Note 1) for fillets |
| Butt Welds<br>Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity.<br>For all other groove welds piping porosity shall not exceed 3/8 in. (9.5mm) in any linear inch of weld and shall not exceed 3/4 in. (19mm) in any 12 in. (305mm) length of weld. | LEVEL O (Note 2)<br>LEVEL B (4 pores 1/16 in.) (Note 1) for butts<br>LEVEL C (4 pores 1/8 in. ) (Note 1) for butts |

**NOTES:** (1) These weld samples illustrate the magnitude of the defect. The permissible distribution is specified in the specification.

(2) Presence of this defect is not permissible. One perfect sample would apply to all cases when the presence of any type of defect is not allowed.

**TABLE III CONTINUED**
**-SCATTERED POROSITY-**

| EXISTING STANDARD | APPLICABLE SAMPLES |
|---|---|
| NAVSEA 0900-LP-003-8000 Paragraph 5.3.2.2 requirement | |
| Linearly aligned rounded indications as defined in 2.19 (four or more indications in a line any one of which is separated from the adjacent indication by less than 1/16" or D whichever is greater, where D is the major diameter of the larger of the adjacent indications), shall be cause for rejection if one or more of the indications is l/32-inch diameter or greater for Class 1 | LEVEL A (4 pores 1/32 in.)(Note 1) for butts and fillets |
| 1/16 inch or greater for Class 2 | LEVEL.B (4 pores 1/16 in.) (Note 1) for butts and fillets |
| 3/16 inch or greater for Class 3 | LEVEL B (4 pores 1/16 in.) (Note 1) for butts and fillets |

NOTE: (1) These weld samples illustrate the magnitude of the defect. The permissible distribution is specified in the specification.

**TABLE III CONTINUED**
**-SCATTERED POROSITY-**

| EXISTING STANDARD | APPLICABLE SAMPLES |
|---|---|
| ASME Section VIII<br>Division 1<br>Appendix 8 Para. 8.3<br>Requirements 8.4 | |
| All surfaces to be examined shall be free of:<br><br>b) Four or more rounded defects in line separated by 1/16 in. (1.6mm) or less (edge to edge) | LEVEL A (4 pores 1/32 in) (Note l)<br>for butts and fillets |

**NOTE** (1) These weld samples illustrate the magnitude of the defect. The permissible distribution is specified in the specification.

TABLE IV

APPLICABILITY OF SAMPLE LEVELS TO VARIOUS SPECIFICATIONS

| | BUTT WELDS | | | FILLET WELDS | | |
|---|---|---|---|---|---|---|
| LEVEL | UN | SCATTERED POROSITY | CLUSTER POROSITY | UNDERCUT | SCATTERED POROSITY | CLUSTER POROSITY |
| A | NAVSEA C1.1<br>ASME<br>AWS D.1.1 | NAVSEA C1.1<br>ASME | not addressed | NAVSEA C1.1<br>ASME<br>AWS D.1.1 | NAVSEA C1.1<br>ASME | not addressed |
| B | NAVSEA C1.2,3<br>ASME<br>AWS D.1.1 | NAVSEA C1.2,3<br>AWS D.1.1 | not addressed | NAVSEA C1.2,3<br>ASME<br>AWS D.1.1 | NAVSEA C1.2,3 | not addressed |
| C | NAVSEA C1.2,3 | AWS D.1.1 | not addressed | NAVSEA C1.2,3 | AWS D.1.1 | not addressed |

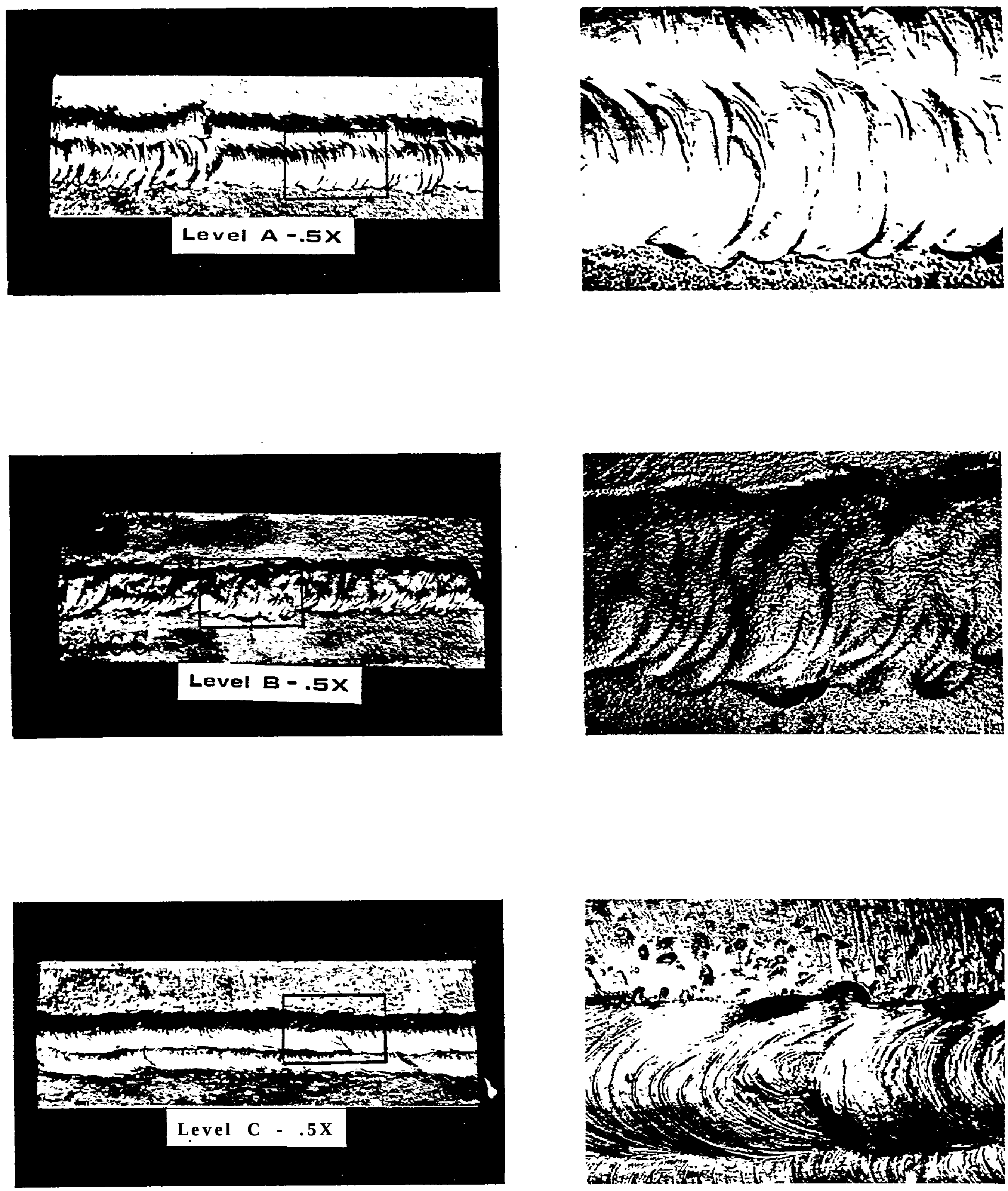


FIG. A: Undercut

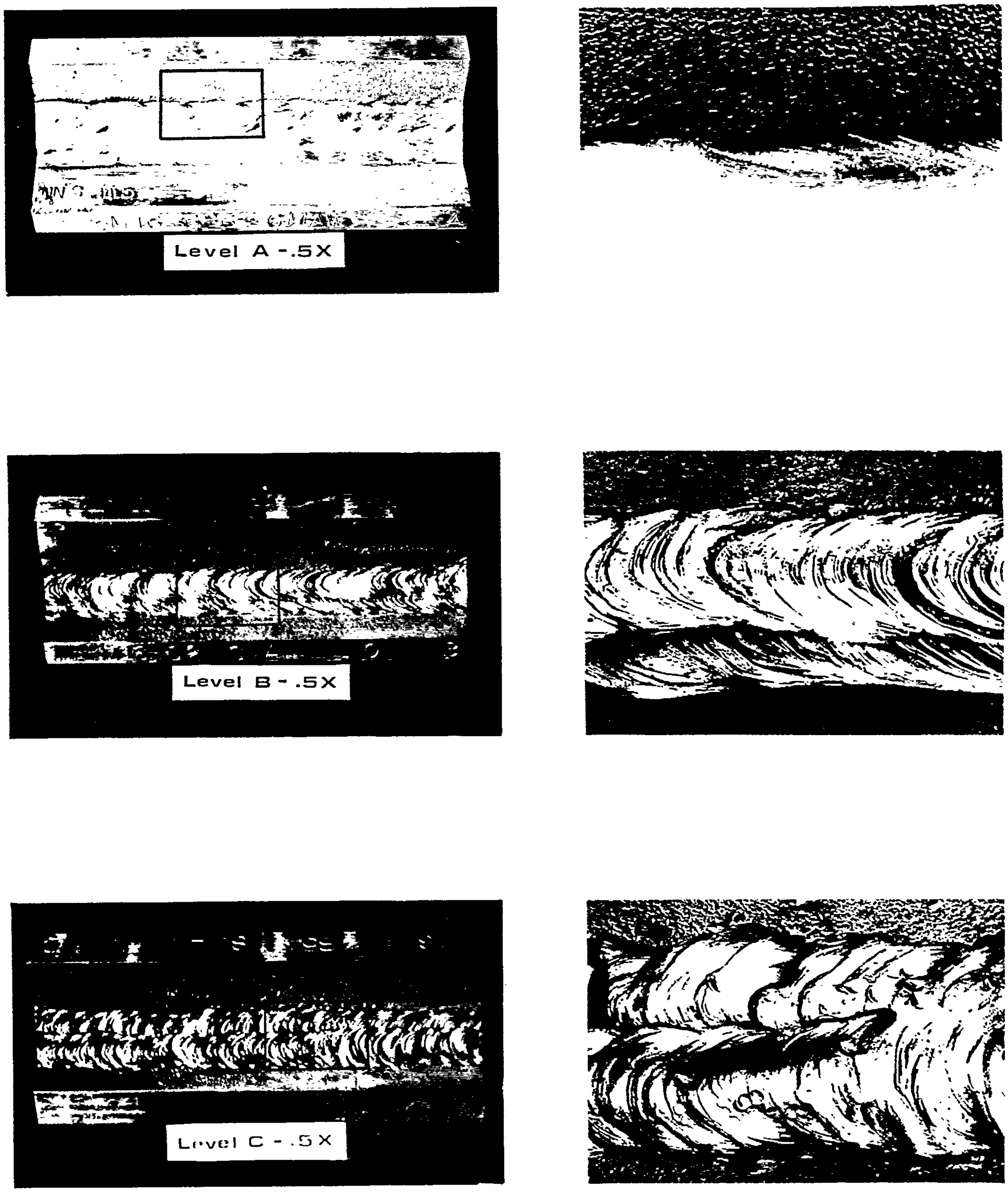


FIG. B: Undercut

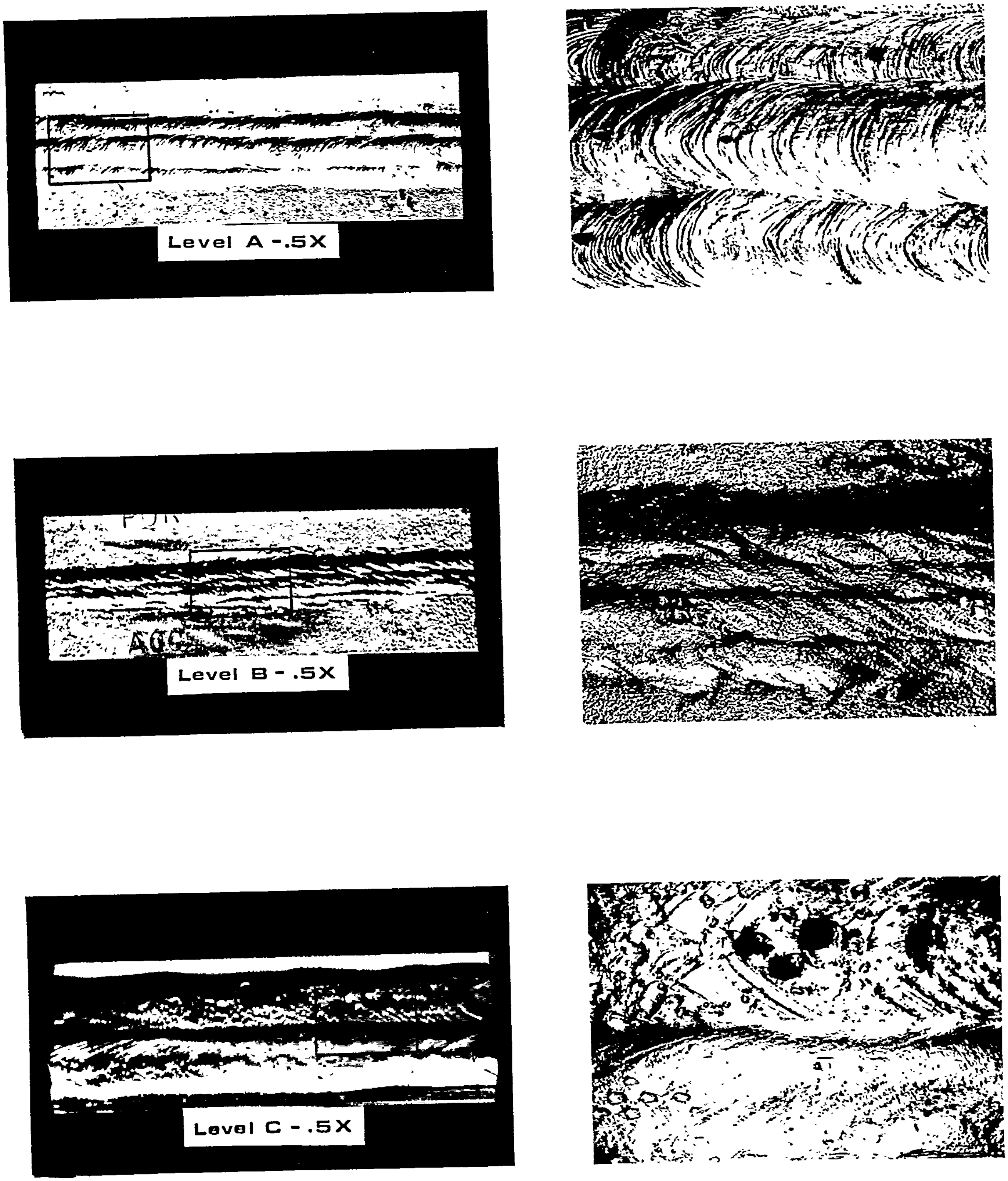


FIG. C: Scattered Porosity

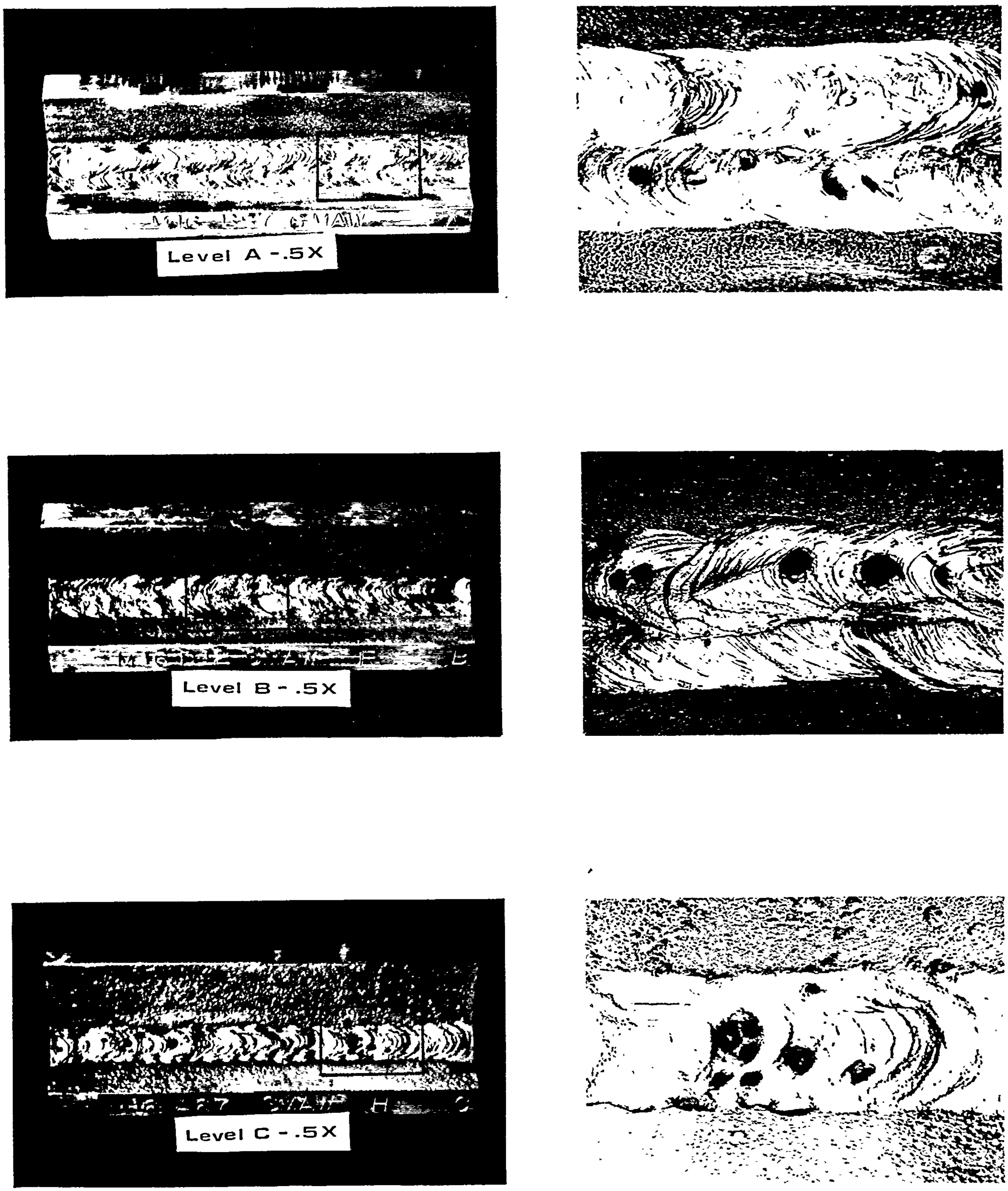


FIG. D: Scattered Porosity

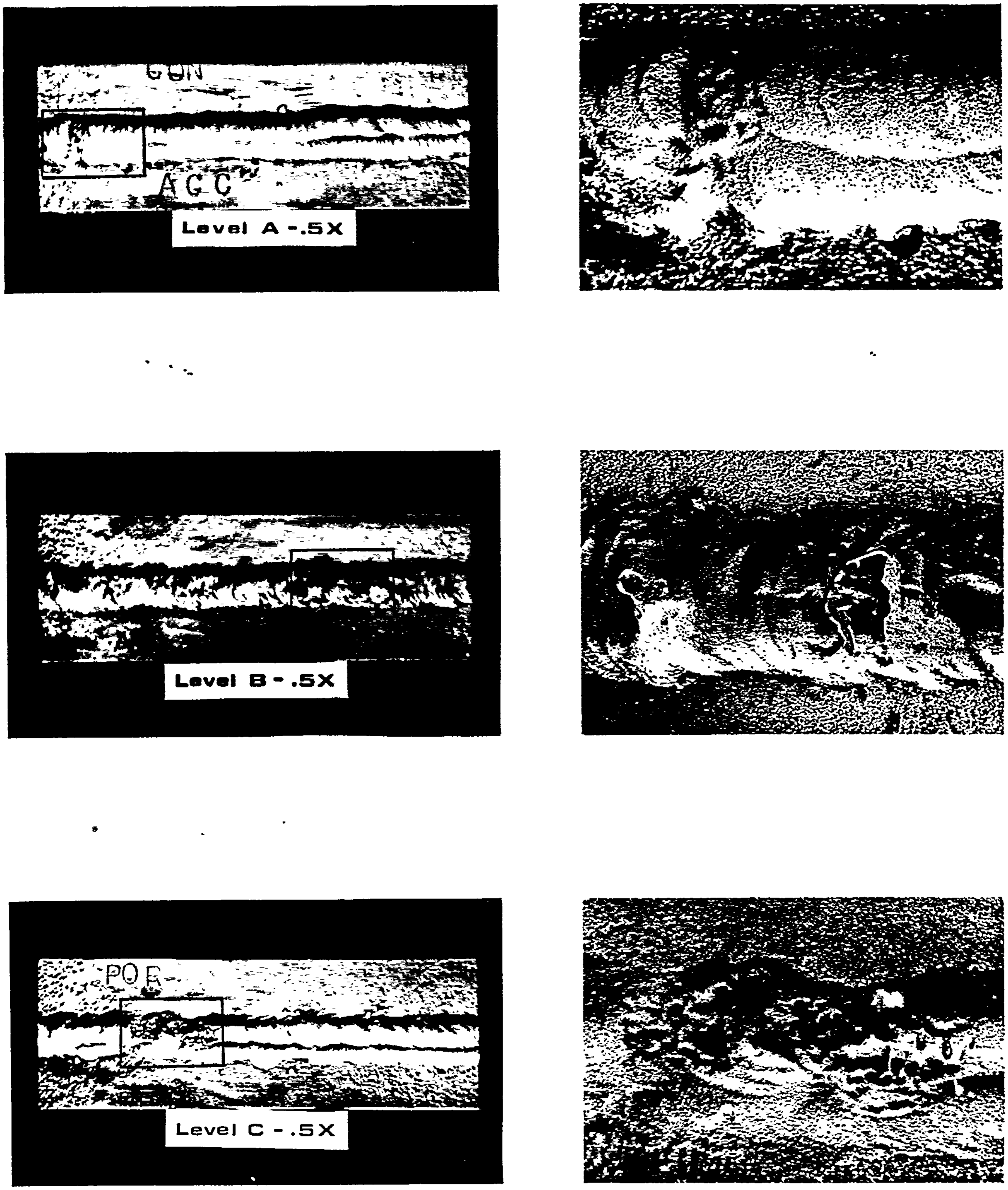


FIG. E: Cluster Porosity


FIG. F: Cluster Porosity